

SAX J1712.6-3739: a persistent hard X-ray source as monitored with *INTEGRAL*[★]

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ABSTRACT

Context. The X-ray source SAX J1712.6–3739 is a very weak Low Mass X-ray Binary discovered in 1999 with *BeppoSAX* and located in the Galactic Center. This region has been deeply investigated by the *INTEGRAL* satellite with an unprecedented exposure time, giving us an unique opportunity to study the hard X-ray behavior also for weak objects.

Aims. We analysed all available *INTEGRAL* public and private Key-Program observations with the main aim of studying the long-term behavior of this Galactic bulge X-ray burster.

Methods. The spectral results are based on the systematic analysis of all *INTEGRAL* observations covering the source position performed between February 2003 and October 2006. SAX J1712.6–3739 did not shows any flux variation along this period as well as compared to previous *BeppoSAX* observation. Hence, to better constrain the physical parameters we combined both instrument data.

Results. Long *INTEGRAL* monitoring reveals that this X-ray burster is a weak persistent source, displaying a X-ray spectrum extended to high energy and spending most of the time in a low luminosity hard state. The broad-band spectrum is well modeled with a simple Comptonized model with a seed photons temperature of ~ 0.5 keV and an electron temperature of ~ 24 keV. The low mass accretion rate ($\sim 2 \times 10^{-10} M_{\text{sun}}/\text{yr}$), the long bursts recurrence time, the small sizes of the region emitting the seed photons consisting with the inner disk radius and the high luminosity ratio in the 40–100 keV and 20–40 keV band, are all features common to the Ultra Compact source class.

Conclusions. We report, for the first time, on the X-ray behavior of this source: observations with unprecedented wide energy band and sensitivity revealed this X-ray burster is a persistent source with an hard spectrum extending up to energies > 100 keV.

Key words. Gamma rays: observations – stars: individual: SAX J1712.65–3739 – stars: neutron – X-rays: binaries

1. Introduction

SAX J1712.6–3739 was discovered in 1999 during the monitoring campaign of the Galactic Centre region performed by the *BeppoSAX*/WFC (Cocchi et al. 1999 and in 't Zand et al. 1999). This instrument observed a type-I X-ray burst with exponential decays on August 1999, identifying the compact object as a weakly magnetized neutron star in a low mass X-ray binary system with a derived distance of 7 kpc (Cocchi et al. 2001). The source was followed-up by the *BeppoSAX*/instruments to investigate the spectral properties: SAX J1712.6–3739 shows a spectrum extended up to about 60 keV, with an intensity of ~ 6 mCrab, both in the MECS (1–10 keV) and in the PDS (15–60 keV). The spectrum was fitted by an absorbed power law ($\Gamma \sim 2.2$) and a column density $N_H \sim 2 \times 10^{22} \text{cm}^{-2}$ or by a Comptonised emission model with electron temperature of ~ 50 keV and a lower column density $N_H \sim 1 \times 10^{22} \text{cm}^{-2}$ (Cocchi et al. 2001). The ROSAT source J171237.1-373834 is just 0'6 from the *BeppoSAX* position with a flux of 1.6 mCrab in the energy range 0.1–2.4 keV (in 't Zand et al. 1999). No optical counterpart has been identified yet within the 13'' (1σ) ROSAT error circle

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radius. SAX J1712.6–3739, monitored during the PCA/RXTE bulge scan program, is continuously active, apparently in two states: a slowly changing state, and a quicker one (in 't Zand et al. 2007). It was included in the IBIS/ISGRI soft Gamma-Ray survey catalog (Bird et al. 2007) as a transient X-ray burster with fluxes corresponding to 4.7 ± 0.1 mCrab and 4.0 ± 0.2 mCrab in the energy bands 20–40 keV and 40–100 keV, respectively. Recently, Chelovekov et al. (2006) reported two further burst detections with *INTEGRAL*/IBIS in 2003–2004, both with the same peak flux.

2. Observations and Data Analysis

BeppoSAX observed the source on September 1999 with an exposure of 21 ksec. LECS, MECS and PDS event files and spectra, available from the ASI Scientific Data Center, were generated by means of the Supervised Standard Science Analysis (Fiore et al. 1999). Both LECS and MECS spectra were accumulated in circular regions of 8' radius. The PDS spectra were obtained with the background rejection method based on fixed rise time thresholds. Publicly available matrices were used for all the instruments. The cross-calibration constant values were taken in agreement with the indications given in Fiore et al. 1999. Fits are performed in the following energy band: 0.5–3.0 keV for LECS, 1.5–10.0 keV for MECS and 15–70 keV for PDS. The *INTEGRAL* (Winkler et al. 2003) observations are divided

into uninterrupted 2000-s intervals, the so-called science windows (SCWs). Wideband spectra (from 5 to 200 keV) of the source are obtained using data from the two high-energy instruments JEM-X (Lund et al. 2003) and IBIS (Ubertini et al. 2003). Data were processed using the Off-line Scientific Analysis (OSA v5.1 and v6.0 for IBIS and JEM-X, respectively) software released by the *INTEGRAL* Scientific Data Centre. While IBIS provide a very large FOV ($> 30^\circ$), JEM-X has a narrower FOV ($> 10^\circ$), thus providing only a partial overlap with the high-energy detectors. Data from the Fully Coded field of view only have been used for both instrument. Two X-ray bursts detected with *INTEGRAL*/IBIS in 2003-2004 reported by Chelovekov et al. (2006) are not included in our data set, being the source out of our selected field of view. IBIS light curves and spectra are extracted for each individual SCW. JEM-X spectrum was extracted from mosaic image at the position of the SAX J1712.6–3739.

3. Spectral Analysis of the persistent emission

During the *BeppoSAX* observations the source intensity was ~ 6 mCrab both in the MECS (2-10 keV) and PDS (15-60 keV) instruments. The SAX J1712.6–3739 flux level after discovery was near the limiting sensitivity of the WFC instrument (Jager et al. 1997) and for this reason this object was classified as a transient source (Cocchi et al. 1999). *INTEGRAL* long monitoring, at the limiting sensitivity of ~ 1 mCrab at 10σ level on an exposure of ~ 10 Ms, shows that SAX J1712.6–3739 is a weak persistent source, with a time averaged intensity of 6.1 ± 0.3 mCrab and 6.7 ± 0.7 mCrab, for IBIS (17-30 keV) and JEM-X (4-10 keV) instruments, respectively. The SAX J1712.6–3739 luminosity do not significantly vary from one observation to another, so that we can take advantages in order: 1) to create an high quality IBIS and JEM-X average spectra with long exposure time (685 ks and 132 ks, respectively) and 2) to build up a wide band spectrum with no gap from 0.5 to 200 keV, combining LECS, MECS, PDS, IBIS and JEM-X data.

The whole data set was fitted with several physical models, using XSPEC v. 11.3.1.

We fitted the spectrum in the energy band 0.5–200 keV with a simple cutoff powerlaw model but this resulted in a poor fit to the data with a reduced chi square $\chi^2_\nu \sim 2.7$ (135 d.o.f.). Similar result ($\chi^2_\nu \sim 3.1$ with 135 d.o.f.) was obtained fitting this data set with the Comptonization model *COMPST* (Sunyaev and Titarchuk 1980).

For both models, the strongest residuals are at the energy below few keV, indicating that a more complex model with a soft component is need to fit these data. This is agreement with the picture formulated in the past years according to which the X-ray spectra of the low mass X-ray binaries were generally described as the sum of a soft and hard component. These in turn are interpreted in the framework of two models: the Eastern Model (Mitsuda et al. 1984) consisting of a blackbody together with a Comptonized component and the Western model (White et al. 1984), consisting of a multicolor disk blackbody plus a Comptonized component. For the soft component we used the black body component in the formulation of Mitsuda et al. (1984) with all parameters free or the multicolor disk blackbody component in the formulation of Makishima et al. (1986), which assume the gravitational energy released by the accreting material is locally dissipated into blackbody radiation, that the accretion flow is continuous throughout the disk, and finally the effects of electron scattering are negligible. The two parameters of this model are free: $r_{\text{in}}(\cos i)^{0.5}$ where r_{in} is the innermost radius of the disk, i is the inclination angle of the disk and

kT_{in} the blackbody effective temperature at r_{in} . Adding a black body component improves the fit significantly, reducing χ^2/dof from 366/135 to 138/133 for the cutoff power law model and from 414/135 to 160/133 for the *COMPST* model. We also have tried to fit this data set with a model consisting of a only one *COMPIT* (Titarchuk 1994) component, assuming a spherical geometry for the Comptonizing region. This replaces the *COMPST* Comptonization model in the sense that the theory is extended to include relativistic effects and the seed photon energy can be in the soft X-ray range, while in the older models the seed photons are cool, i.e. in the UV band. We left the following parameters free: the temperature of the Comptonizing electrons kT_e , the plasma optical depth τ_p and the input temperature of the soft photon Wien distribution kT_0 . This model gives a good χ^2/dof of 142/134 and also take care of the photons deficit below few keV with respect to the cutoff powerlaw or *COMPST* models. The physicals parameters obtained using this model are reported in Table 1. Adding a soft X-ray component to the *COMPIT* component reduces $\chi^2/\text{d.o.f.}$ from 142/134 to 119/132 for the black body component and from 142/134 to 120/132 for multicolor disk blackbody component, with a low F-test chance probabilities of 8.6×10^{-6} and 1.5×10^{-5} , respectively. These fit results of the broad band spectrum using the models with two emission components are reported in Table 1.

The column density N_{H} towards the source was left free and its value measured by the LECS and MECS instrument is always close to the galactic column density ($N_{\text{H galactic}} = 1.34 \times 10^{22} \text{ cm}^{-2}$, estimated from the 21 cm measurement of Dickey & Lockman 1990). Figures 1, 2 and 3 show the counts spectra with residuals respect to the best fits and the photon spectra of the SAX J1712.6–3739 using the models described above. These figures clearly illustrate the importance of the broad band coverage obtained combining *INTEGRAL* and *BeppoSAX* data, which allowed us to well constrain the physical parameters and clearly shows the source has a constant luminosity from ~ 3 up to 20 keV.

4. Discussion

INTEGRAL observations reveal for the first time that this X-ray burster is a persistent source, displaying a very hard X-ray spectrum and spending most of the time in a low luminosity and hard state. A broad-band spectrum obtained combining the *INTEGRAL* together with the *BeppoSAX* data displays properties which fits well into the classification of low luminosity ($\sim 0.01 L_{\text{Edd}}$) weakly magnetized neutron stars with "hard spectra" (Barret et al. 2001): a broad-band spectrum extending up to 100 keV, dominated by a Comptonized component, with a optical depth of the Comptonizing corona of ~ 3 , seed photons temperature of ~ 0.5 keV, an electron temperature of ~ 24 keV. A few LMXBs appear to spend most of the time in this "hard state" (Di Salvo & Stella 2002), e.g. 4U 0614+091 (Piraino et al. 1999) or 4U1850-087 (Sidoli et al. 2006).

The emission spectrum could be also fitted with a two component model consisting of a blackbody, or multi color blackbody component which represents emission from an optically thick accretion disk or from the neutron star surface, together with a Comptonized component which is interpreted as emission from a hot inner disk region or a boundary layer between the disk and the neutron star. We have estimate a black body radius of ~ 5 km for the black body component and the inner radius of the disk $< 11 \text{ km}$ for the multi disk component. Although the data statistics does not allow us to distinguish between the two

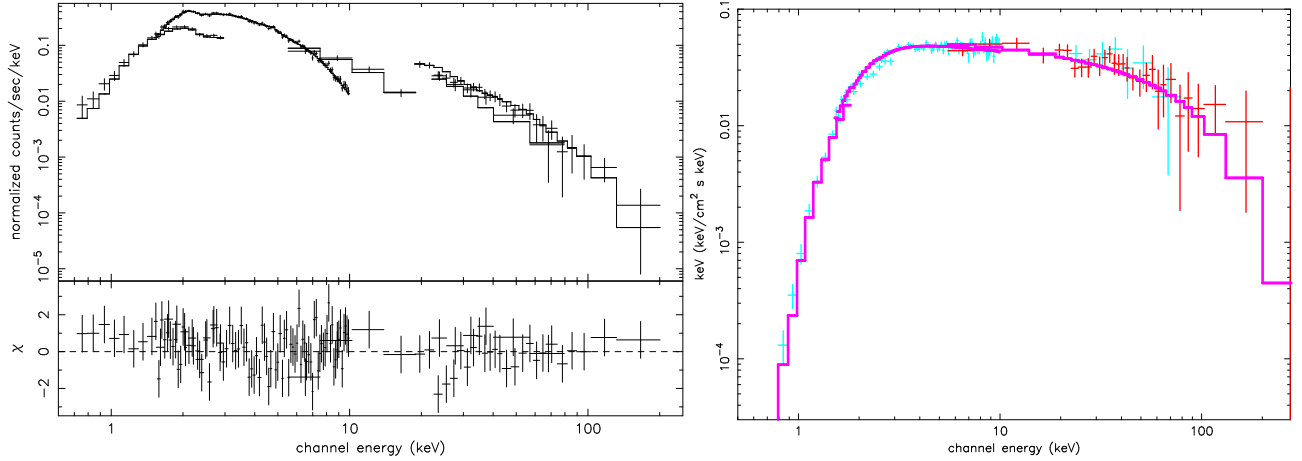


Fig. 1. *INTEGRAL* and *BeppoSAX* data and residuals respect to the best model consisting of a simple comptonized COMPTT model (left) and respective energy spectrum (right). Light blue points are *BeppoSAX* data and red points are *INTEGRAL*.

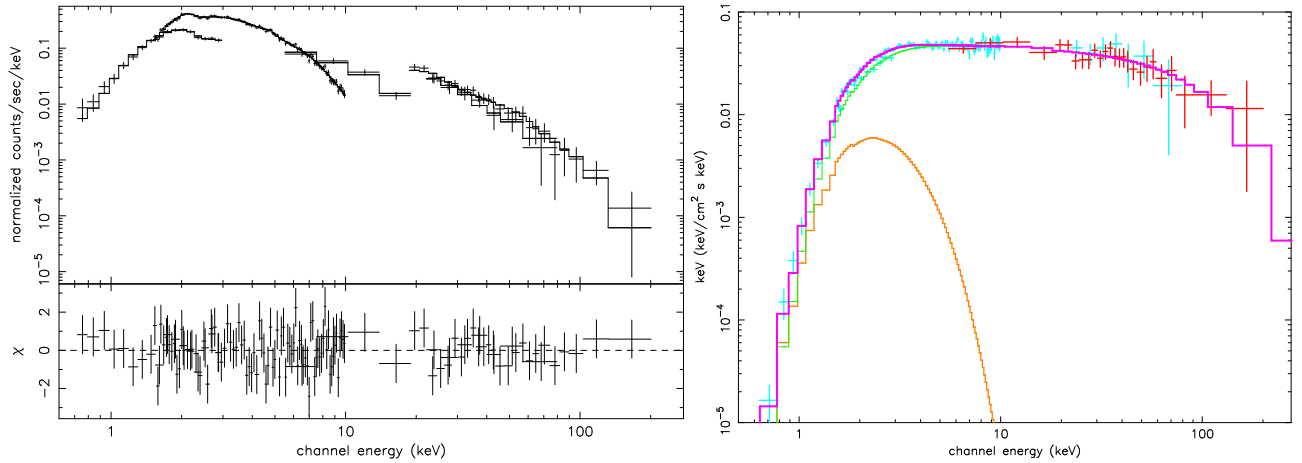


Fig. 2. *INTEGRAL* and *BeppoSAX* data and residuals respect to the best model consisting of a multicolor black body and Comptonized COMPTT model (left) and respective energy spectrum (right). Light blue points are *BeppoSAX* data and red points are *INTEGRAL*. The contributions of the two component are shown separately: orange and green are multi color black body and Comptonization component, respectively, and their sum is plotted in magenta.

physical models, both values of the radius give an indication of the system compactness.

We have also estimated the sizes of the emitting seed photons region, assuming their emission as blackbody with temperature T_0 and radius R_{seed} following in 't Zand et al. (1999). We obtain $R_{seed} \approx 8.3 \text{ km} (L_C/10^{37} \text{ erg s}^{-1})^{1/2} (1+y)^{-1/2} (kT_0/1 \text{ keV})^{-2}$, where L_C is the luminosity of the Comptonization component. Here, we have estimated the amplification factor of the seed luminosity by the Comptonization as $(1+y)$, where y is the Comptonization parameter, $y = 4kT_e \max(\tau, \tau^2)/m_e c^2$. The obtained values are $\sim 1 \text{ km}$ and $\sim 10 \text{ km}$ for the model with the blackbody component and with multicolor disk blackbody component, respectively. The parameters obtained using the latter model allows for a more reasonable interpretation.

These results show that the radius of the region providing the seed photons for the Comptonization emission is consistent with the inner radius of the accretion disk, showing that the seed photons are bounded in small region spatially coincident with the inner part of the disk. Moreover the seed photons temperature T_0 is consistent with the inner disk temperature T_{in} . By imposing $T_0 = T_{in}$, the fit values correspond to a disk temperature of $0.57 \pm 0.08 \text{ keV}$ with a χ^2/dof of 121/133. This behavior suggests to identify the inner disk as the region providing the

seed photons of the Comptonization emission. This result was observed in most of ultra compact X-ray source: 4U 1850-087, 4U 1820-303 and 4U 0513-40 (Sidoli et al. 2001), XTE J1751-305 (Gierliński & Poutanen 2005), XTE J1807-294 (Falanga et al. 2005).

Assuming the persistent flux represents the average mass accretion rate and an accretion efficiency of $\eta = 0.2$ (corresponding, e.g., to $M_{NS} = 1.4 M_\odot$ and $R_{NS} = 10 \text{ km}$) and using multi color disk model luminosity, $L_{0.1-200 \text{ keV}} = 1.6 \times 10^{36} \text{ erg s}^{-1}$, we get $\dot{M} \approx 2.8 \times 10^{-10} M_\odot \text{ yr}^{-1}$ for SAX J1712.6-3739. This low mass accretion rate is consistent with the hard spectrum of SAX J1712.6-3739, according to our present understanding on the X-ray bursters (for review see van der Klis 2006). Moreover, the burst recurrence time is dependent on the mass accretion rate on the neutron star: the faster new fuel is provided from the donor star, the shorter is the burst recurrence time. Long *INTEGRAL* monitoring shows clearly that the frequency of bursts in this sources is low, as previously reported by in 't Zand et al. (2007), who estimated a recurrence time of 345–6507 hr.

In 't Zand et al. (2007) have selected all 31 persistent X-ray bursters as reported in the *INTEGRAL* survey (Bird et al. 2006) and demonstrated that the low mass accretion rates are accompa-

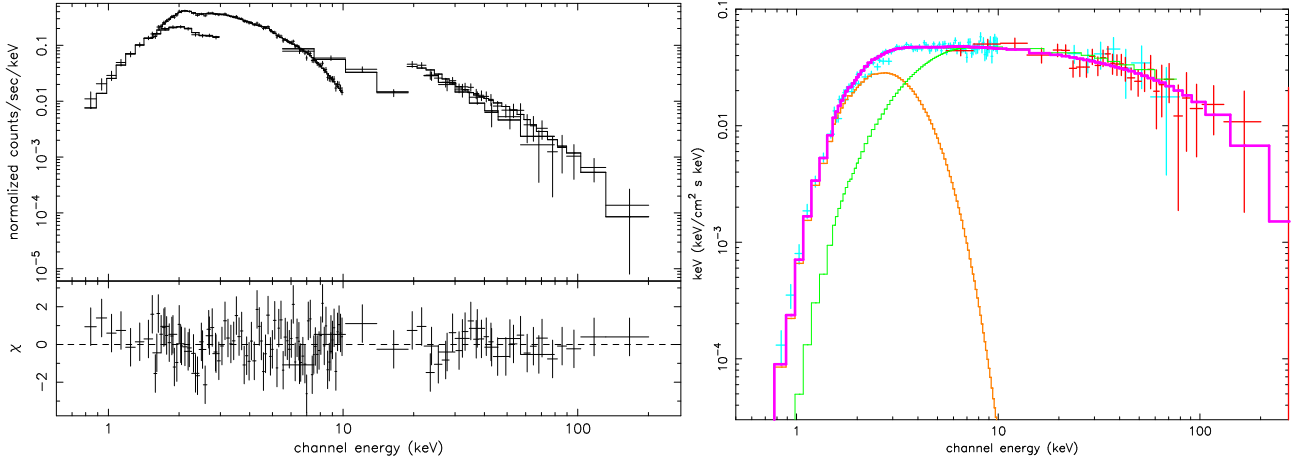


Fig. 3. *INTEGRAL* and *BeppoSAX* data and residuals respect to the best model consisting of a simple black body and a Comptonized COMPTT model (*left*) and respective energy spectrum (*right*). Light blue points are *BeppoSAX* data and red points are *INTEGRAL*. The contributions of the two component are shown separately: orange and green are black body and Comptonization component, respectively, and their sum is plotted in magenta.

Table 1. Results of the SAX J1712.6–3739 fit, using different models: a simple comptonized model, a blackbody plus a Comptonized component and a multicolor disk blackbody plus a Comptonized component. Uncertainties are at the 90% confidence level for a single parameter variation.

Model 1	N_H (10^{22} cm^{-2})	...	...	T_0 (keV)	T_e (keV)	τ ...	n_{COMPTT} (10^{-3})	$\chi^2/\text{d.o.f}$...
<i>comptt</i>	1.3 ± 0.1	...	...	0.47 ± 0.02	24^{+16}_{-10}	2.7 ± 1.3	$2.0^{+1.2}_{-0.8}$	142/134
Model 2	N_H (10^{22} cm^{-2})	T_{in} (keV)	$r_{\text{in}}(\cos i)^{0.5}$ (km)	T_0 (keV)	T_e (keV)	τ ...	n_{COMPTT} (10^{-3})	$\chi^2/\text{d.o.f}$...
<i>diskbb + comptt</i>	1.4 ± 0.3	0.7 ± 0.3	< 11	0.5 ± 0.2	24^{+22}_{-9}	3 ± 2	$1.6^{+1.6}_{-0.8}$	120/132
Model 3	N_H (10^{22} cm^{-2})	T_{bb} (keV)	R_{bb} (km)	T_0 (keV)	T_e (keV)	τ ...	n_{COMPTT} (10^{-3})	$\chi^2/\text{d.o.f}$...
<i>bbbody + comptt</i>	1.2 ± 0.2	0.6 ± 0.1	5 ± 1	1.2 ± 0.2	34^{+54}_{-14}	2.0 ± 1.5	$0.5^{+0.6}_{-0.2}$	119/132

nied by the hard X-ray spectra of the persistent emission. Almost all the Ultra Compact X-ray binaries have the highest values of the (40–100)keV/(20–40)keV hardness ratio. SAX J1712.6–3739 was not included as supposed to have a transient nature. We now know it is a persistent and weak source, showing a high ratio $L_{(40-100)\text{keV}}/L_{(20-40)\text{keV}} \sim 0.90$, in agreement with the value of 0.85 ± 0.06 as derivated from recent data in Bird et al. 2007. Finally, the low mass accretion rate, the long bursts recurrence time, the small sizes of the region emitting the seed photons consisting with the inner disk radius and the high luminosity ratio in the 40–100 keV and 20–40 keV support the idea of In ’t Zand et al. (2007) that this source could be a candidate Ultra Compact Binary.

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References

- Barret, D. 2001, in *Adv. Space Res.*, 28, 307
- Bird A. J., et al., 2006, *ApJ*, 636, 765
- Bird A. J., et al., 2007, *ApJ* S, in press
- Chelovekov, I.V., Grebenev, S.A., & Sunyaev, R.A., 2006, *AstL*, 32, 456 (astro-ph/0605638)
- Cocchi, M., Natalucci, L., in ’t Zand, J.J.M., et al. 1999, *IAUC* 7247
- Cocchi, M., Bazzano, A., Natalucci, L., Heise, J., & in ’t Zand, J.J.M. 2001, *Mem. S.A.It.*, 72, 757
- Dickey & Lockman, 1990, *Ann. Rev. Astron. Astrophys.* 28, 2
- Di Salvo, T., & Stella, L. 2002, proceedings of the XXII Moriond Astrophysics Meeting, The Gamma-Ray Universe (Les Arcs, March 9-16, 2002), ed. A. Goldwurm, D. Neumann, & J. Tran Thanh Van (Vietnam: The Gioi Publishers) [arXiv:astro-ph/0207219]

- Falanga, M., Bonnet-Bidaud, J. M., Poutanen, J., Farinelli, R., Martocchia, A., Goldoni P., Qu J. L., Kuiper, L., Goldwurm, A., A&A, 2005, 436, 647
- Fiore, F., Guainazzi, M., & Grandi, P. 1999, Cookbook for BeppoSAX NFI Spectral Analysis (www.asdc.asi.it/bepposax/software/cookbook)
- Gierliński, M., & Poutanen, J., 2005, MNRAS, 359, 1261
- in 't Zand, J.J.M., Heise, J., Bazzano, A., Cocchi, M., & Smith, M.J.S. 1999, IAUC 7243
- in 't Zand, J.J.M., Markwardt, C.B., Bazzano, A., et al. 2002, A&A, 390, 597
- in 't Zand, J.J.M., Jonker, P. G., & Markwardt C. B., 2007, A&A, accepted.
- Jager et al., 1997, A&AS, 125, 557
- Lund, N., et al., 2003, A&A, 411, L231
- Makishima K., Maejima Y., Mitsuda K., et al., 1986, ApJ 285, 712
- Mitsuda, K., Inoue, H., Koyama, K., Makishima, K., Matsuoka, M., Ogawara, Y., Suzuki, K., Tanaka, Y., Shibasaki, N., Hirano, T., 1984, PASJ, 36, 741
- Piraino, S., Santangelo, A., Ford, E. C., Kaaret, P., 1999, A&A, 349, 77
- Sidoli, L., Parmar, A.N., Oosterbroek, T., Stella, L., Verbunt, F., Masetti, N., & Dal Fiume, D. 2001, A&A, 368, 451
- L. Sidoli, A. Paizis, A. Bazzano, S. Mereghetti, 2006, A&A, 460, 229.
- Sunyaev and Titarchuk, 1980, A&A, 86, 121
- Titarchuk L., 1994, ApJ 434 570
- Ubertini, R., Lebrun, F., di Cocco, G. et al. 2003, A&A, 411, 131
- Van der Klis, M., 2006, in "Compact Stellar X-ray Sources", eds. W.H.G. Lewin and M. van der Klis, CUP (Cambridge, UK).
- White N. E., Stella L. & Parmar A. N., 1988, ApJ, 324, 363
- Winkler, C., Gehrels, N., Schnfelder, V., Roques, J.-P., Strong, A. W., Wunderer, C., Ubertini, P., 2003, A&A, 411, 349